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GIS ANALYSIS OF AVERAGE MONTHLY SPECIFIC RUNOFF IN SLOVENIA

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Abstract: Water cycle research is the basis of any water management and one of most important elements is the runoff. In environmental analyzes the most commonly used is the annual specific runoff. Due to increasing environmental awareness the need for better seasonal runoff knowledge is crucial to support the decision making processes in order to improve the sustainable water resources management. The water quantity is crucial for all environmentally based water management. For water vulnerability analyzes the specific runoff can be taken into account as water sensitivity indicator. Since the runoff is varying in time and space the average annual runoff is not always enough, the substantial improvement can be achieved with the use of seasonal or monthly runoff. With the use of GIS we joined the results of two hydrological analyzes: water balance and river flow regimes. We used kriging to transform the point data of discharge coefficients in order to create continuous spatial distribution of the variable as a raster. To compute long-term average monthly specific runoff raster we used mathematical functions in GIS to combine the long-term specific runoff raster and the monthly discharge coefficients. The final results are 12 raster maps of monthly discharge coefficients and 12 maps of long-term monthly specific runoff.

Keywords: *hydrology, specific runoff, river flow regime, kriging, GIS*

I. INTRODUCTION

The study of water cycle elements is the basis for any systematic water management. Water cycle consists of three main elements: precipitation, evapotranspiration and runoff. Runoff is the amount of water flowing from the surface or through the ground from the watershed area. Runoff and specific runoff are the basic hydrological information about one of the main elements of the water cycle. For Slovenia only the long-term specific runoffs have been analyzed so far

(Kolbezen and Pristov, 1998; Frantar, 2008) and the first continuous GIS raster map of the long-term annual specific runoff for the territory of Slovenia was made in the analysis of water balance for the period 1971 – 2000 (Frantar, 2008) . There are no maps or rasters of specific monthly runoff for Slovenia yet, although important and useful, especially in the analysis of pressures and driving forces on water. The main aim is to describe the methodology to calculate monthly runoffs with the use of monthly discharge coefficients and annual runoff raster data sets and to show the results – the average monthly runoff maps.

Slovenia is central European country lying in the border of four main European regions. These regions (Fig. 1) have great influence on all of the elements of hydrological cycle with its natural and human-induced characteristics that differ distinguishly between the regions. Most of Slovenia is headwater area with the Alpine and Subalpine mountains in the northwest and Dinaric Mountains in the southeast. The Mediterranean and Panonian characteristics are found in southwest and in the northeast of the country. There are only two main transit rivers: the Mura River and the Drava River flowing into from Austria.

Fig. 1 Slovenia and its main physio geographical regions

II. DEFINITIONS AND METHODOLOGY

Specific runoff indicates the quantity of water flowing from a particular territory in specific time interval. It is usually expressed in liters of water per second or in millimeters per year (Mikoš et al., 2002; Frantar, 2008). It shows the how "wet" the watershed is (Špes et al., 2002).

Seasonal distribution of runoff is very uneven (Plut, 2000) and therefore the pressures on water environment and ecosystems are not uniform throughout the year. Monthly amount of runoff is therefore very important because it shows more realistic water discharge state and hence seasonally different sensitivity of the aquatic environment. Since the average low discharges in rivers (Špes et al., 2002) are a very good indicator of the sensitivity, we can conclude that also the lowest monthly runoffs are a good indicator of surface water sensitivity. This is particularly true in the months of water scarcity and drought when these monthly runoff indicators are far better water vulnerability indicators than the average annual specific runoff.

In terms of environmental analysis, the higher specific runoff means better stream self-cleaning ability. The streams in these conditions are less sensitive to pollutants' impacts and vice versa (Špes et al., 2002). It is also known that the society's impacts on water have different intensity (Špes at al., 2002; Plut, 2004).

Average monthly amounts of water in streams are discussed in different analyzes of river discharge regimes. Discharge regime is an indicator of the average river discharge fluctuations over the year. Factors that influence discharge regimes are many and varied but the most important are: climate, topography, bedrock, soil, vegetation and society. The most important factor here is climate as the discharge regimes depend mainly on the annual distribution of precipitation, evapotranspiration, temperature and the duration of snow cover (Hrvatin, 1998; Frantar and Hrvatin, 2005).

In Slovenia there are several research papers (Stele, 1987; Kolbezen and Pristov, 1998; Hrvatin, 1998; Frantar and Hrvatin, 2005; Frantar, 2005) on this subject, but unfortunately all are focused on the point of the river gauging stations and they are not discussing the geographical distribution of the phenomenon. We used the discharge regime as basic factor on which we have calculated the average monthly specific runoffs.

Geographic information systems allow various analyzes of physic-geographical features of the landscape that include also the hydrological analysis. Crucial for the analysis are water gauging stations on surface waters. The most important parameter for the rivers is discharge, which we can equal to runoff in most cases. In GIS river gauging station is defined as point data on the linear object (river) and its data reflects the conditions of the entire upstream watershed area – polygon. Therefore raster maps of a specific runoff are difficult to obtain and are calculated on the basis of the climatic water balance method where the runoff is the difference between precipitation and evapotranspiration (Kolbezen and Pristov, 1998; Frantar, 2008). The role of river gauging stations and the runoff data in the long-term case is to verify the results of the precipitation and evapotranspiration raster data. The purpose of river discharge data was that of control layer.

In the analysis of specific monthly runoff in Slovenia the GIS tools were used to combine, join the point river gauging stations discharge data and the raster data of the specific runoff for the period 1971 - 2000. The main input raster set, the average annual runoff for the period 1971 - 2000 in Slovenia has been calculated and published in the Water Balance 1971 - 2000 (Frantar, 2008). The second source is the point discharge data from river gauging stations, which were used to calculate the monthly discharge coefficients. Based on point values, the monthly coefficient raster sets were created. Monthly coefficient raster sets were used to multiply (to weight) the long term annually specific runoff raster. The results are average specific runoff raster sets for each month in Slovenia.

Monthly discharge coefficients represent the relationship between the monthly and the annual runoff and, based on that, we conclude also that they represeny the relationship between monthly and annual specific runoffs.

Since in Slovenia there are no raster maps of specific monthly discharges we decided to create them with the combination of specific annual runoff raster and monthly discharge coefficients. The calculated raster maps provide the overlook of the monthly quantities of the internal runoff (Plut, 2000). As a result, the internal water volumes are useful for further water management analyses as they represent the water availability in every raster cell (Plut, 2000).

III. DISCHARGE COEFFICIENTS AND MONTHLY RUNOFF MAPS

In Slovenia there have been over 700 river gauging stations operational so far. In the period of 1971 – 2000, we have reviewed the data of 166 river gauging stations. The missing data were filled in with the use of linear correlation from the most comparative gauging station that operated in the missing time period. The comparative station also must have high statistical confidence level to the missing station.

Monthly discharge coefficients were calculated from the full monthly data series of the period 1971 - 2000 using the simple formula:

$$MDC = \frac{AMD}{AAD}$$

where:

MDC - monthly discharge coefficient;

AMD - average monthly discharge;

AAD - average annual discharge.

Analysis of the appropriateness and adequacy of the data was made on 166 river gauging stations. Since the specific runoff reflects the characteristics of all the watershed area, some water gauging stations had to be excluded from the set. From the set we excluded the stations with to big hinterland, the stations on transitional rivers and the stations that showed high deviations of hydrological characteristics to neighboring stations. High deviations usually show a strong likelihood of errors in the data or the presence of greater artificial influence on the discharge regime (Kolbezen and Pristov, 1998; Frantar, 2008).

The commonly used method for raster creation out of point data is interpolation. It was used in the process of creation of all used raster sets. The interpolation is a method assuming that the spatial distribution of the modeled variables is continuous or at least partially continuous. We assess the value of the field based on a limited number of sample points (de Smith et al., 2009). One of the methods of spatial interpolation is the kriging, which is a group of geostatistical techniques used to interpolate the value of a random field at an unobserved location from observations of its values at nearby locations (Wikipedia, 2010).

Kriging method gives good results in modeling the space where points and it takes into account spatial autocorrelation of the variables (Zagmajster et al., 2008). There are several types of kriging and the universal kriging is already acknowledged as one of the best methods for the interpolation of precipitation (Kastelec and Košmelj, 2002). Modeling of local average values gives local polynomial trend surface (de Smith et al. 2009; ESRI, 2007). Universal kriging was chosen also in the long-term water balance 1971-2000 analysis where the precipitation and the evapotranspiration raster’s were created. With this method these two layers were the basis to compute the raster layer of average long-term specific runoff that is the first layer used in this analysis as input data (Frantar, 2008).

The interpolation of discharge coefficient point data to raster was made based on 120 gauging stations for all 12 months (Fig. 1). In our case we have interpolated data by using universal kriging with linear drift based on the twelve nearest points. Linear drift was used because the main factors influencing the specific runoff were already taken into account when the raster maps of precipitation and evapotranspiration were created. This suggests that also the long-term specific runoff raster has the correction factors already incorporated and that therefore the distribution of variable between the gauging stations' points can be simply linear. The local, internal physic-geographical characteristics of the landscape are presumed to be already included (IWP, 2001).

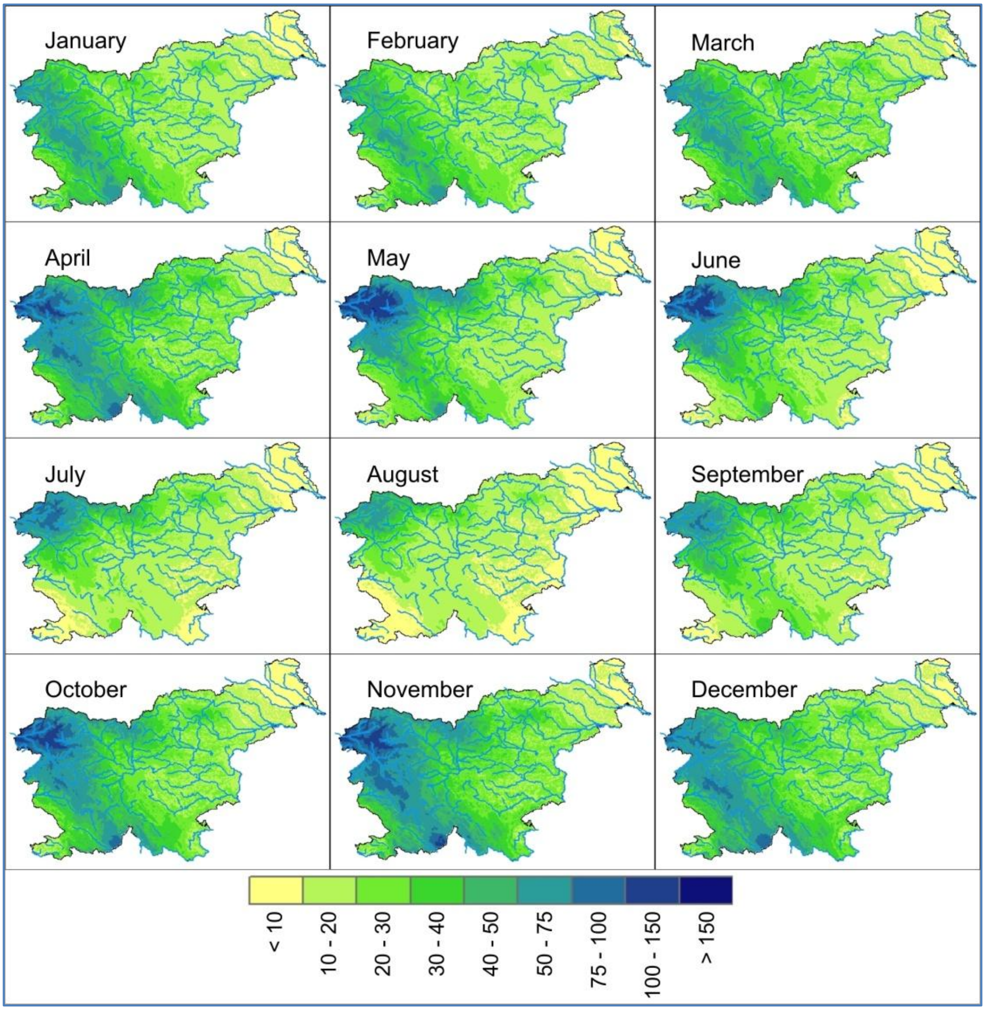

Fig. 2 Average monthly discharge coefficients in period 1971-2000

The average monthly specific runoff raster's were made by computation of discharge coefficient raster and the long-term specific runoff raster with multiplication of these two raster sets (Fig. 3 shows the main elements of the whole process). As a result of the multiplication for every month the average specific monthly runoff raster was created (Fig. 2).

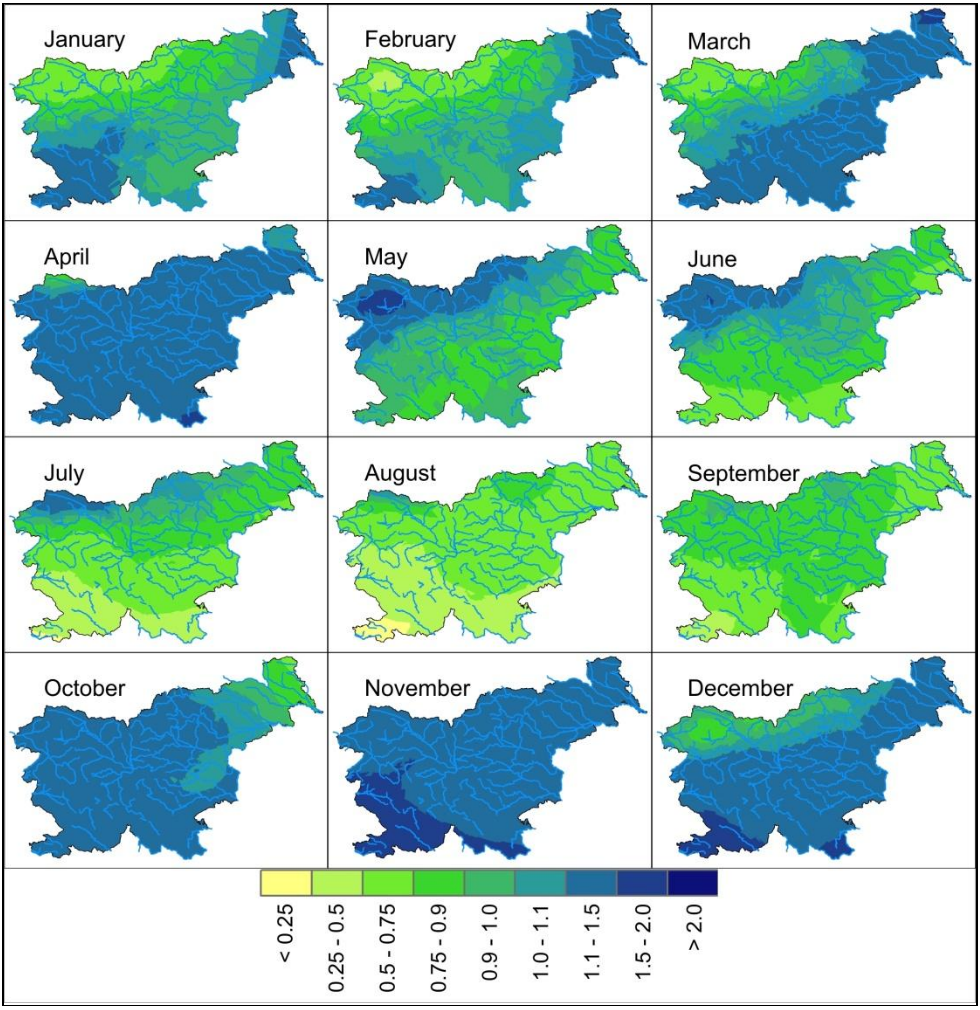

Fig. 3 Average monthly runoff (mm) mm in period 1971-2000

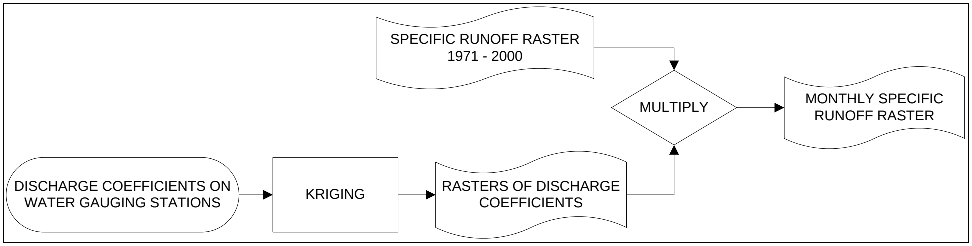

Fig. 4 Scheme of GIS multiplication process in monthly specific raster creation

IV. CONCLUSIONS

The analysis of the monthly specific runoff in Slovenia has not been implemented until this research. By using a combination of two hydrological statistical spatial analyses we produced new hydrologic data. With the use of GIS and quantitative analysis we obtained new information, we mined out new knowledge, on the basis of two previous analyses.

General overview of the discharge coefficient rasters shows that the highest discharge coefficients in Slovenia are in April and November and the lowest in August. But due to high regional variability this tendency is not linear all over the country. Especially during the wintertime it is seen that the discharge is lower in mountainous regions in the northwest of Slovenia from December to March due to snow retention. The overview of the specific runoff shows big temporal and spatial variability over the months also due to high spatial runoff variability in Slovenia. It is seen that the least variability in the monthly specific runoff is in August and February and the highest is in May and June. The geographical distribution of the runoff is highly dependent upon landscape characteristics.

Hydrological results have important new value and reflect the conclusions of the previous point analysis of discharge regimes with the spatial distribution as the main added value. The new information is the key to understand the spatial distribution of specific runoff in each month separately. Because the internal drainage (runoff) is not linear over the year, seasonal variations are of particular importance to aquatic and riparian ecosystems which now can be seen from monthly specific runoff maps that are now presented in a grid format. The new monthly specific runoff rasters can help to implement sustainable water management as these allow new approaches for seasonal water management. That is a step forward compared to more static yearly water management.

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